RESEARCH DEPARTMENT

Surface-wave feeders for u.h.f. site tests

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SUMMARY

This report describes experimental surface-wave feeders and launching horns for use with balloons for u.h.f. site tests. The general problems associated with the design of this type of transmission system are discussed together with the results on some practical feeders and horns.

1. GENERAL

When testing a site for a u.h.f. television station it is necessary to radiate a test transmission from an aerial situated at the same height above ground as that of the final aerial if a good prediction of the service area is to be obtained. It is also necessary to test with several different aerial heights in order to find the most economic mast height to use. Since the final mast height may be up to 1,250 ft (410 m) the only practical way of raising the aerial is with a balloon.

If the service transmitter is to have an effective radiated power (e.r.p.) of 500 kW it is found that, using the best receivers available at the present time[1,2], an e.r.p. of 10 W is necessary to enable the final service area to be predicted.

When the work on the feeders described in this report was started, it was not possible to make suitable light weight u.h.f. transmitters. During the last year, however, advances in varactor multipliers have changed this situation, and it is now possible to obtain solid state sources giving 10 W output at 800 Mc/s and weighing less than 6 lb (2·7 kg).

The type of balloon used for site tests is a Mk VI kite balloon of 2,500 cu. ft (70 cu. m) capacity. This balloon has a lift of approximately 65 lb (30 kg) in still air and requires a flying cable of 10 to 20 cwt. (500 to 1,000 kg) breaking strain. With the transmitter on the ground the payload has to be shared between the combined tethering and feeder system and the transmitting aerial. The only type of feeder for u.h.f. which can be made with low loss, light weight and sufficient mechanical strength for tethering the balloon is a surface-wave feeder[3]. Even so, presently available feeders of a suitable type are marginally adequate in strength-to-weight ratio. The feeder should also include a second insulated conductor to permit a power monitor at the balloon to operate a meter on the ground.

Launching horns are necessary at each end of the feeder. The main requirements as discussed in Section 4 include low coupling loss, good matching, lightness and ability to slide along the feeder.

2. SURFACE-WAVE FEEDERS

A surface-wave feeder has a central conductor with a surface covering such that the wave velocity is reduced near the conductor. This is normally achieved by a thin coating of a low loss dielectric such as polythene. Providing that the thickness of the dielectric is very small compared with the wavelength of the transmitted signal, the thicker the coating the more closely the energy is confined to the surface of the feeder. A thick coating reduces any radiation losses due to bending of the feeder, but it introduces additional weight and dielectric losses. For a static installation the optimum thickness usually occurs when the radial thickness of the dielectric is equal to the diameter of the conductor. For a balloon feeder, however, weight restrictions normally necessitate the use of much thinner dielectric coverings. A curve showing the energy distribution around the balloon cable[4] described below is shown in Fig. 1.

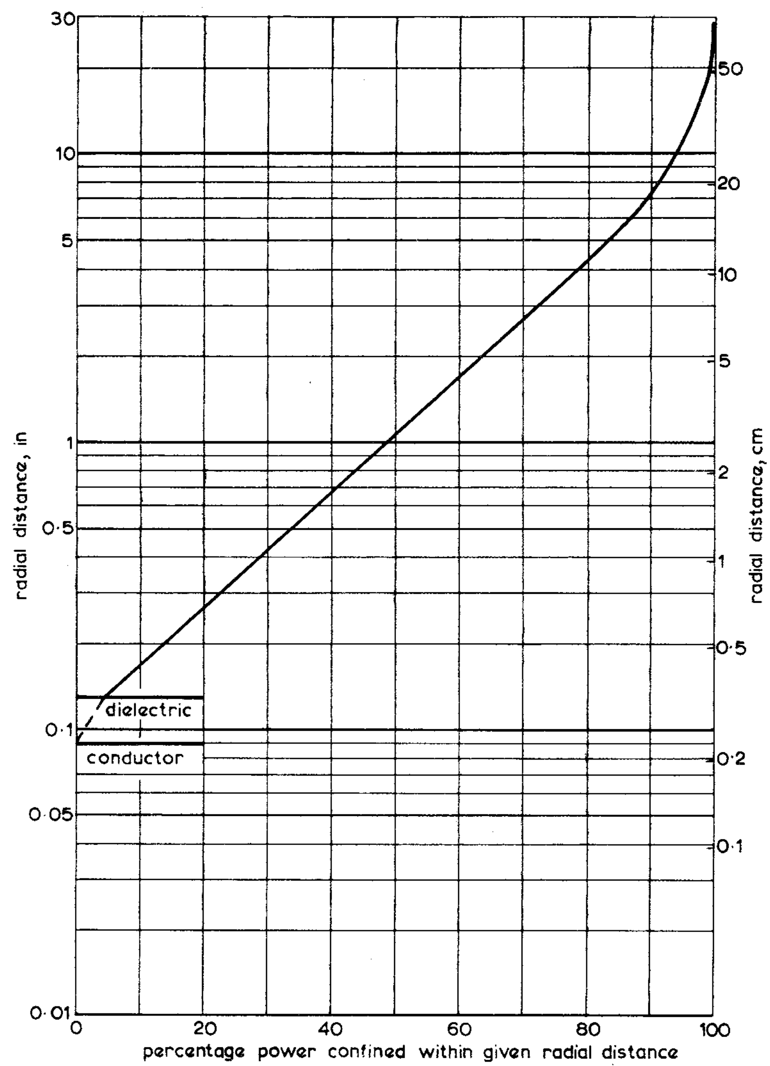

Fig. 1

Power distribution around balloon feeder at 600 Mc/s

3. SURFACE-WAVE FEEDER BALLOON CABLE

Preliminary tests on a surface-wave feeder consisting of a seven-strand copper conductor covered by a thick layer of polythene (the inner of UR 67 coaxial cable) confirmed the accuracy of published design data.[4,5,6] On this basis the design of a balloon cable was started. The general mechanical design of this cable followed that of an earlier balloon cable (Telcon type T.P.626) which, whilst suitable mechanically, was designed only for use at power frequencies. Since the conductors in the feeder require good conductivity as well as mechanical strength copperweld (copper-coated steel) wire was used for all conductors. An inner conductor of seven strands of 30 SWG copperweld wire insulated with 0·037 in. (0·94 mm) of polythene was surrounded by 19 strands of 24 SWG copperweld and covered overall with 0·04 in. (1 mm) of black polythene. During manufacture, difficulties arose in holding the outer conductors tight whilst passing through the outer extruding machine, and it became necessary to bind these conductors into position. The first solution tried was to use a 0·005 in. (0·127 mm) 'Melinex' tape over the copperweld. Measurements of feeder loss on this cable show four times the expected attenuation and this is believed to be due to the Melinex being insufficiently strong to hold the copperweld strands in good contact with one another. A second cable was then completed using 0·004 in. (0·1 mm) copper tape over the copperweld. This cable had an attenuation closer to the calculated value, but the copper tape gave a considerable increase in weight and made the cable stiff and difficult to handle. Also, such a cable is likely to have a poor mechanical life.

The make up of the cable was determined entirely by the required breaking strain, low bending losses and satisfactory extrusion of the polythene outer during manufacture.

Since the balloon cable was manufactured, measurements on a sub-miniature coaxial cable (S.T. & C. type LCR 24014) with a braided outer conductor and P.T.F.E. covering have been made. Although this cable is not very suitable as a surface-wave feeder, the results show only a small increase of attenuation due to the conductor being braided instead of solid.

It is now apparent that a better design of balloon cable would consist of a stranded high tensile steel core, nylon insulated, with a braided copper outer conductor and an overall covering of polythene. Such a cable would have a greater strength to weight ratio than the existing cable and would be more flexible.

4. LAUNCHING HORNS

In order to connect the surface-wave feeder to the transmitter and aerial a coupling arrangement is required between the feeder and coaxial cables. The simplest arrangement is to use a launching horn at each end of the feeder. The main requirements of these horns are as follows:

(a) They should give a good match to the surface-wave feeder.

(b) They should be of low loss.

(c) They should be of light weight but of such a size and construction as to be readily handleable. This applies particularly to a balloon-borne horn.

(d) In the case of the ground-based horn, it must allow the feeder to slide through it during operation.

Requirement (d) enables the balloon to be flown and recovered by winding in the feeder and also permits height gain measurements to be made. If the match to the feeder is not good, then the resulting power changes due to feeder reflections whilst the balloon height is changed, will give false impressions of the height-gain characteristic as it is not practical to correct these power changes nor correlate these changes with the received signal changes.

The type of horn generally used in the past has been a conical horn with a half angle of about 30° connected directly to the feeder or, for better mechanical strength, by means of a quarter wave stub as shown in Fig. 2. This type of horn has been found to have a very poor bandwidth when a good match is required and it reflects a comparatively large amount of power back along the surface-wave feeder. The match of this shape of horn can be improved only by (a) greatly increasing the horn size, (b) changing the shape of the feeder within the horn, or (c) using a dielectric lens within the horn. The first and last of these possibilities are excluded on weight grounds, whilst the second is ruled out if the feeder must slip through the horn without damage to its outer dielectric. For these reasons it was decided to investigate the improvements that might be given by a different shape of horn. The problem of sliding the horn along the feeder is considered separately.

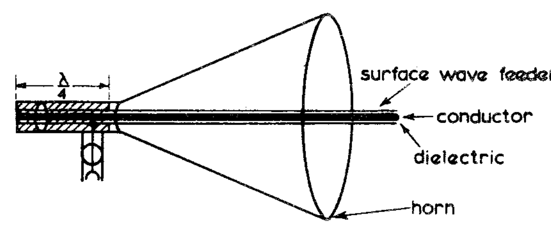

Fig. 2 - Conical horn

5. THE IMPROVED LAUNCHING HORN

The mismatch losses of a launching horn are derived from two separate sources. Since the horn is not of infinite size some power will escape past the outer edge of the horn and be lost (horn diameter loss); also, since a practical horn cannot have a very gradual taper, a component of the incoming signal will, in general, be reflected when it meets the horn. The optimum horn shape must minimise both these sources of loss.

The two main assumptions made in calculating the optimum horn shape for this application are:

(a) The overall weight should not change for different horns. This, for all practical shapes, is entirely determined by the slope length of the horn.

(b) The optimum shape will occur when losses due to the two causes previously described are approximately equal.

If for a given horn the diameter is increased, then the length must be reduced. These changes will reduce the energy passing the outer edge but will increase the reflected energy. An examination of the energy distribution around the cable[4] as in Fig. 1 shows that nearly all of the energy flows within 7·5 in. (19 cm) of the conductor. This energy distribution is almost exponential from the conductor up to a radial distance containing 90% of the energy. Beyond this distance the rate of fall of energy is somewhat slower. Since the energy is concentrated near to the conductor a reflection in this region is more serious than one at a considerable distance from the conductor. If the horn is shaped so that the power reflected from its surface is the same for equal increments of radius at all distances up to the 90% power contour then its shape will be found to be exponential. Beyond this region the law differs and an approximately conical horn is required; the optimum slope for this conical section has a half angle of about 60°.

The horn may be further improved by reducing reflections from the inner portion of the horn by suitable dielectric loading. This will lead to a small increase in the slope at the outside of the horn to regain the minimum loss condition. If the horn is filled with dielectric up to a convenient diameter e.g. the 60% power contour at 1¾ in. (4·5 cm) radius, and the dielectric is appropriately tapered towards the centre conductor, the wave front becomes perpendicular to the cable and the condition for minimum mismatch loss is obtained. This condition requires a conical horn of such a slope as to merge evenly into the exponential sections on either side. In practice mechanical considerations necessitate a steeper taper of the dielectric than that required for minimum mismatch loss but even so, the conical horn is a satisfactory compromise.

The throat diameter of the horn, should be such as to give a characteristic impedance equal to that of the final coaxial feeder. In the horn for the balloon feeder, this has been chosen to be 72 ohms to suit the sliding section of the horn.

In order to reduce weight it is advantageous to skeletonise the outer regions of the horn. The wires used should not be spaced more than $\lambda/8$ apart around the circumference of the horn. Since the spacing of the wires increases as the horn diameter increases the field penetration will gradually increase, necessitating a small reduction in horn angle.

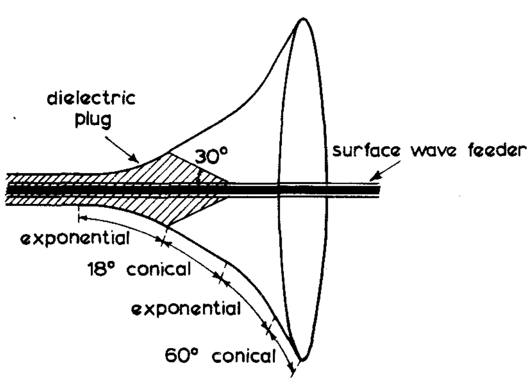

Fig. 3 - Improved horn

The final shape of the horn, Fig. 3, is a polythene filled exponential horn from the throat up to the 50% power contour followed by a conical horn with the dielectric tapering at 30° to the conductor. At the end of this taper the horn changes to a skeletonised form with an exponential surface until the 90% power contour is reached when the horn changes to a conical horn to its final diameter, that of the 95% power contour.

6. THE SLIDING SECTION OF THE HORN

The arrangements to permit the horn to slide along the cable are shown in Fig. 4. They necessitate the use of resonant lines, which limit the bandwidth over

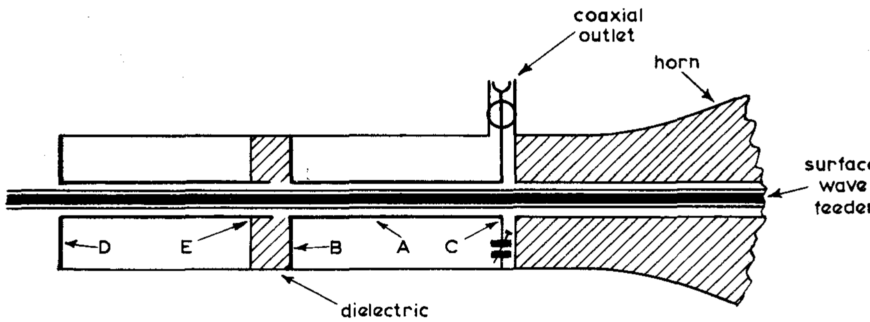

Fig. 4 - Sliding section of horn

which a good impedance match is maintained. Mechanical requirements also limit the range of impedance suitable for good matching and a value of 72 ohms was chosen for the output impedance of the horn. The surface-wave feeder is fitted with a sleeve, A, which, with the surface-wave feeder as inner conductor, provides a quarter-wave length of low impedance line at mid-band. The end remote from the horn is shorted to the horn by a disc B. Since the inner of this sleeve is open-circuited at the disc an effective short circuit at r.f. is obtained between the sleeve and the inner cable at point C to which the inner conductor of the outgoing feeder is attached. A capacitor is connected between the sleeve and the horn at C in parallel with the inductance formed by outer section of line and is tuned so as to give a resistive output impedance. The inner cable open circuit near the short circuit B is improved by a similar sleeve and disc D. The outer cavity of this is tuned by a dielectric plug E which gives mechanical support to the sleeve.

The horn is completely free to move along the feeder since all the sleeves are a loose fit. By using a number of interchangeable sliding sections a considerable frequency coverage may be obtained. The principal power limit of the horn is the output feeder (PT29M) with a power rating of 200W at 600 Mc/s. The next limiting factor is the surface-wave feeder within the horn with a power rating of 600W at 600 Mc/s. The surface-wave feeder itself has a mean power rating of 2 kW. A photograph of the complete horn with sliding sections is shown in Fig. 5.

7. PERFORMANCE

The specification and performance of the copper-tape surface-wave feeder and of two types of horn are given below.

Conductor diameter	0·17 in.	(4·3 mm)
Overall diameter	0·25 in.	(6·4 mm)

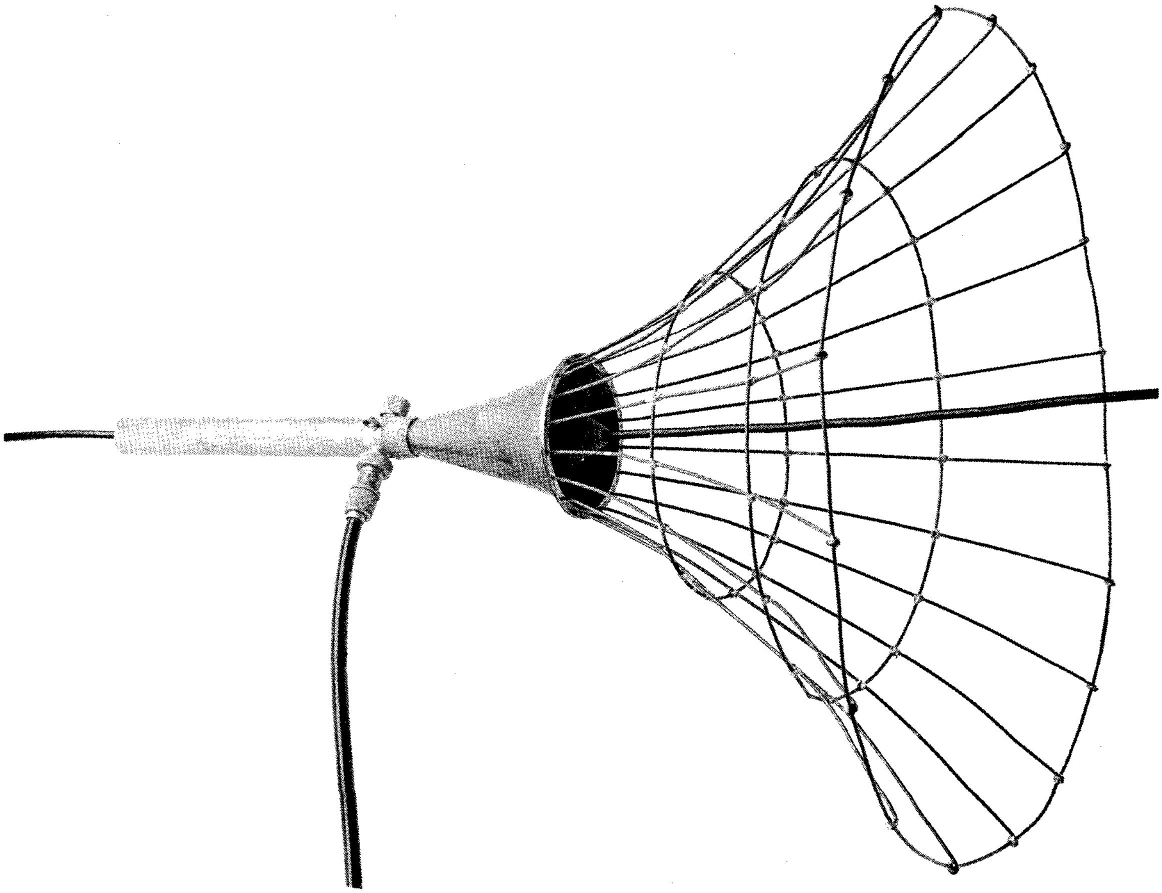

Fig. 5 - Photograph of horn

Weight	0·059 lb/ft	(0·088 kg/m)
Phase velocity/velocity of light in free space	0·98	
Impedance	290 ohms	
Calculated conductor loss at 600 Mc/s	0·0026 dB/ft	(0·0086 dB/m)
Calculated dielectric loss 600 Mc/s	0·0003 dB/ft	(0·001 dB/m)
Calculated total loss 600 Mc/s	0·0029 dB/ft	(0·0097 dB/m)
Measured loss 600 Mc/s	0·0042 dB/ft	(0·014 dB/m)
Estimated sag loss[7], for typical flying conditions at 1,250 ft (410 m)	0·5 dB	

Launching horns

	Conical Horn (Fig. 2)	Improved Horn (Fig. 3)
Horn length	20 in. (51 cm)	17 in. (43 cm)
Mouth diameter	15 in. (38 cm)	21 in. (53 cm)
Total weight	2·9 lb (1·3 kg)	2·9 lb (1·3 kg)
V.S.W.R. at 522 Mc/s	0·96	0·99
V.S.W.R. 470 - 590 Mc/s	>0·65	>0·94
Calculated horn diameter loss	0·45 dB	0·2 dB
Calculated horn reflection loss	0·4 dB	0·2 dB
Calculated total horn loss	0·85 dB	0·4 dB
Measured horn loss	0·8 dB	0·4 dB
Total loss for 1,250 ft (410 m) balloon height		7 dB approx.

8. DISCUSSION OF RESULTS

From the above results it will be seen that a satisfactory electrical performance has been obtained. The overall weight of the feeder in its present form is rather high and the mechanical strength barely sufficient although these could be improved by a redesign as suggested in Section 4. Other problems which require further development are (a) a satisfactory method of attaching the cable to the balloon, and (b) fixing aircraft warning markers to the cable. The attachment of the cable to the balloon should permit the cable to pass through the horn so that the horn can be removed from the cable for frequency changes and also for transport. It is not possible, however, to use the standard crossover attachment as the polythene has too low a coefficient of friction to prevent slipping. This low friction also makes the fixing of aircraft warning markers difficult. Any attachment to the feeder between the horns gives rise to a discontinuity and hence unwanted radiation. Wind loading by these markers may also give sharp bends in the cable giving additional losses.

With the advent of solid state sources weighing less than 6 lb and giving 10W of output at frequencies up to 800 Mc/s, it was considered that an arrangement using these sources would be less liable to damage and easier to handle than one requiring a surface-wave feeder and terminating horns. Development work to overcome the difficulties mentioned above was therefore stopped but, if a much higher power than 10W were ever required for balloon tests, the application of surface-wave feeders would be reconsidered.

9. OTHER APPLICATIONS

It appears that surface-wave feeders of the type discussed can be considered as a means of achieving low loss in any temporary u.h.f. system with a feeder run in the open exceeding about 150 ft (45 m). For certain applications, however, such as television broadcasting, it is known that the level of delayed signals arising from reflexions and the effect of bad weather on the feeder loss may be important and would therefore require separate investigation outside the scope of this report.

If tests from a small 250 cu. ft (7 cu. m) plastic balloon are required up to a height of 200 ft (60 m) it may be possible to use a lightweight cable such as BICC type T3204 and small horns of 10 in. (25 cm) mouth diameter. The overall loss of a 200 ft (60 m) system would be about 4 dB and the weight about 3 lb (1·4 kg).

10. REFERENCES

1. 'U.H.F. Field Strength Measuring Receivers', Research Department Report No. K-164, Serial No. 1963/43.

2. 'A U.H.F. Amplifier and Distribution Unit', Research Department Report No. G-089, Serial No. 1964/16.

3. BARLOW, H.M. and BROWN, J.: 'Radio Surface Waves', Clarendon Press, 1962.

4. GOUBAU, G.: 'Surface Waves and Their Application to Transmission Lines', J. appl. Phys., November 1950, **21**, pp. 1119 - 1128.

5. GOUBAU, G.: 'Designing Surface-Wave Transmission Lines', Electronics, April 1954, **27**, pp. 180 - 4.

6. GOUBAU, G.: 'Single Conductor Surface-Wave Transmission Lines', Proc. Inst. Radio Engrs. 1951, **39**, 6, pp. 619 - 24.

7. GOUBAU, G. and SHARP, C.E.: 'Investigations with a Model Surface-Wave Transmission Line', I.R.E. Trans. Antennas Propag. 1957, **AP-5**, 2, pp. 222 - 27.

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